



Background on Washington State's Petroleum Geology

William S. Lingley, Jr., Chief Geologist
Washington State Department of Natural Resources
Land Management Division

Introduction

On November 3, 2005, a public auction for leasing of State-owned lands for oil and gas will be held in Olympia. Industry or the public may nominate any unleased State lands managed by Washington's Department of Natural Resources (DNR).

Nominations will be accepted until October 3, 2005. In addition to nominations from industry or the public, DNR is offering lands for lease within several blocks shown on the attached map (Plate 2), and defined on the basis of the play concepts briefly described below. In the following discussion, papers describing the geology, geochemistry, reservoir characteristics, stratigraphy, structure, and tectonics of Washington State are cited in the attached bibliography.

Geology

Most of western and southeastern Washington appears to be underlain by thick sequences of Eocene sandstone, siltstone, shale, and coal (Fig. 1). These contain acceptable- to good-quality reservoir and source intervals. The Eocene section is overlain in much of the state by thick sections of clay-rich Oligocene and younger strata (Fig. 2), which may act as a regional seal. Notable exceptions are present in Miocene rocks along Washington's coast and Oligocene rocks in the western Columbia Basin where good to exceptional quality reservoirs are locally present.

Structure in central and eastern parts of the state is chiefly controlled by high-angle oblique slip faults that create numerous large anticlines (Fig. 3). The largest are included in the Yakima Fold belt of the Columbia Basin where several untested anticlines exceed 60-miles in length and two-miles in width (visible on Plate 2 as prominent east-trending ridges, east of the Cascade Range in south-central Washington). A large folded thrust belt with abundant oil shows and stripper oil production forms an accretionary wedge along the coastal margin of the State and extends about 200 miles offshore (Fig. 3, west side and Fig. 4).

To date, only 60 wildcats have been drilled to depths greater than 6,000 feet in this area about half the size of the State of Louisiana. Most recent exploration has keyed on the potential for coalbed methane. However, many areas of the Columbia River Basin,

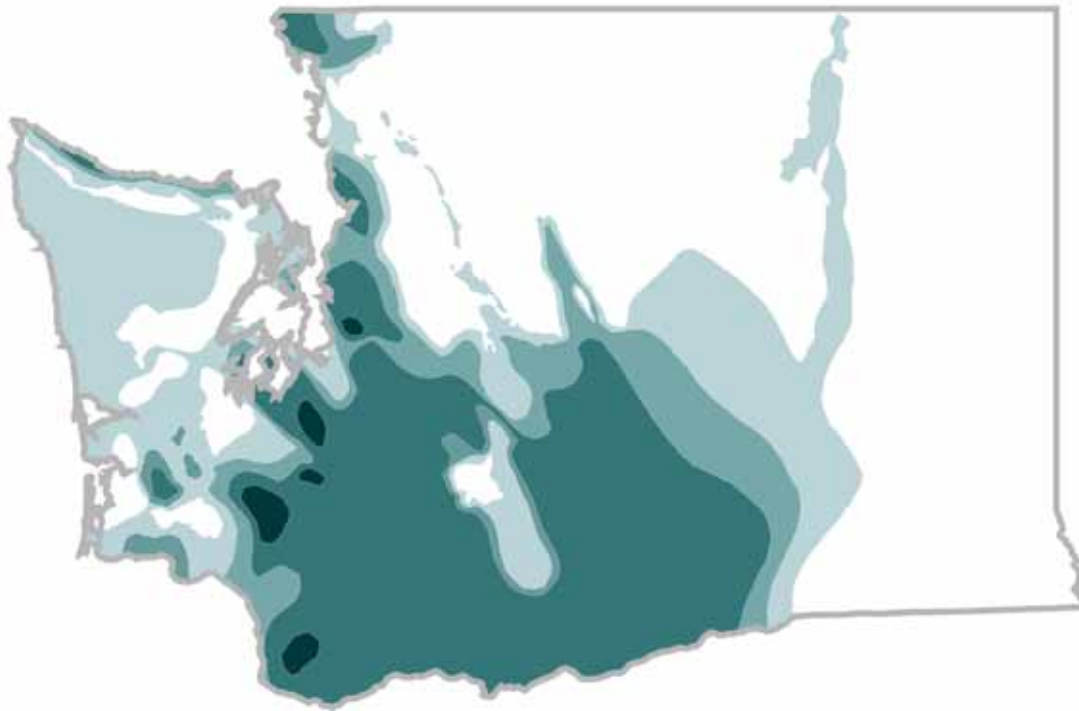
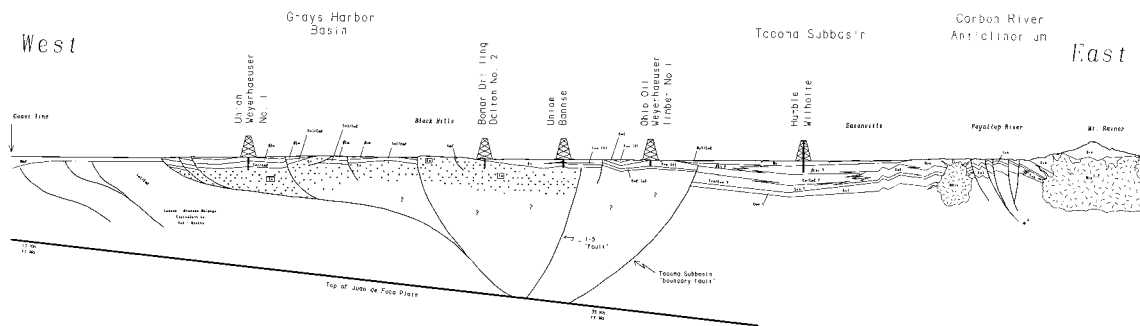
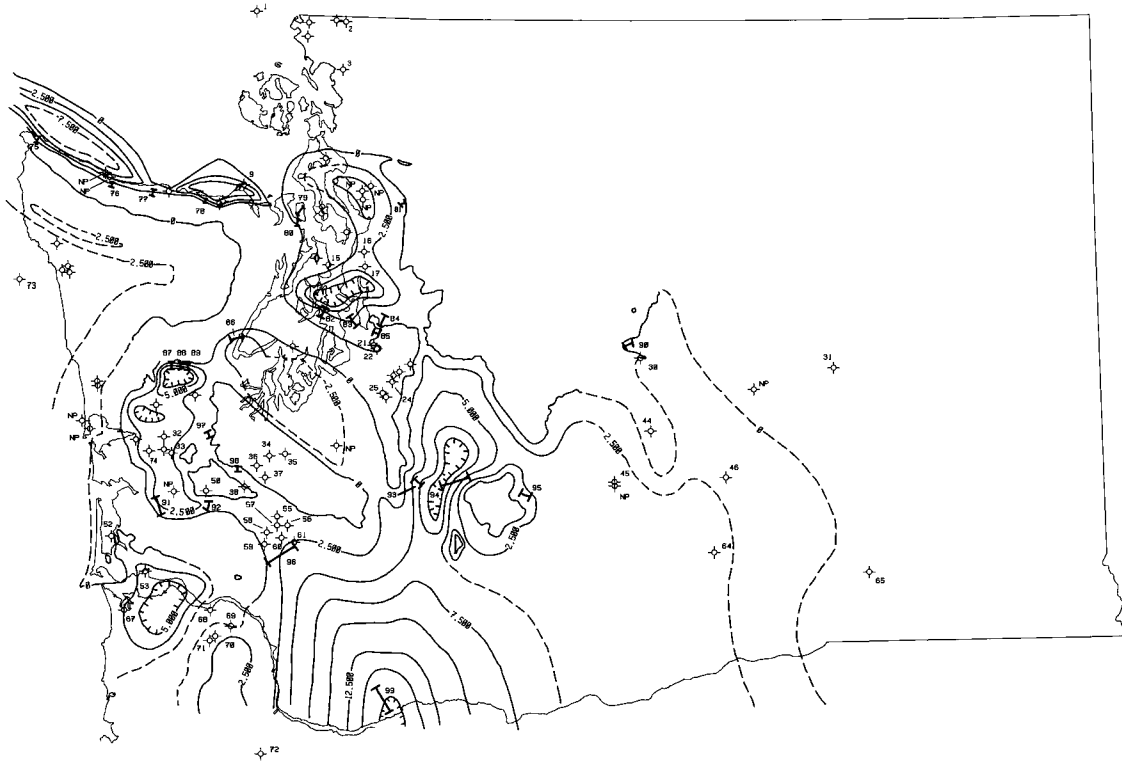


Figure 1. Speculative isochore showing the possible thicknesses of Eocene basin-fill sequences in Western Washington, including some volcanogenic rocks (Walsh and Lingley, 1996). Areas underlain by Eocene rocks and within gas-generative thermal regimes may be considered as prospective. White areas probably have no preserved Eocene strata. Formline contour interval is 5,000 feet.

Puget-Willamette Trough, and southern Cascade Range have potential for conventional natural gas accumulations within large faulted anticlines (Johnson and others, 1997; Lingley, 1995; Lingley and von der Dick, 1991; McFarland, 1983; Walsh and Lingley, 1996). Deep basin-centered gas is the apparent target of ongoing exploratory drilling in the Columbia Basin (Encana Anderville Farms No. 1), but no basin-centered gas exploration has occurred in the Puget-Willamette Trough or along coastal Washington. Potential for oil exploration is best in coastal areas, where oil seeps and shows are common (Snively and Kvenvolden, 1989; Palmer and Lingley, 1989).

Although significant production has not occurred, small amounts of gas were produced from the Bellingham Gas Field east of Ferndale in northwest Washington (McFarland, 1983) and from the Rattlesnake Hills Gas Field north of Richland in the Columbia Basin of Eastern Washington (Fig. 5). The most recent production, which was from the Ocean City Gas and Oil Field west of Aberdeen, ceased in 1962. No oil or gas has been produced since that time.



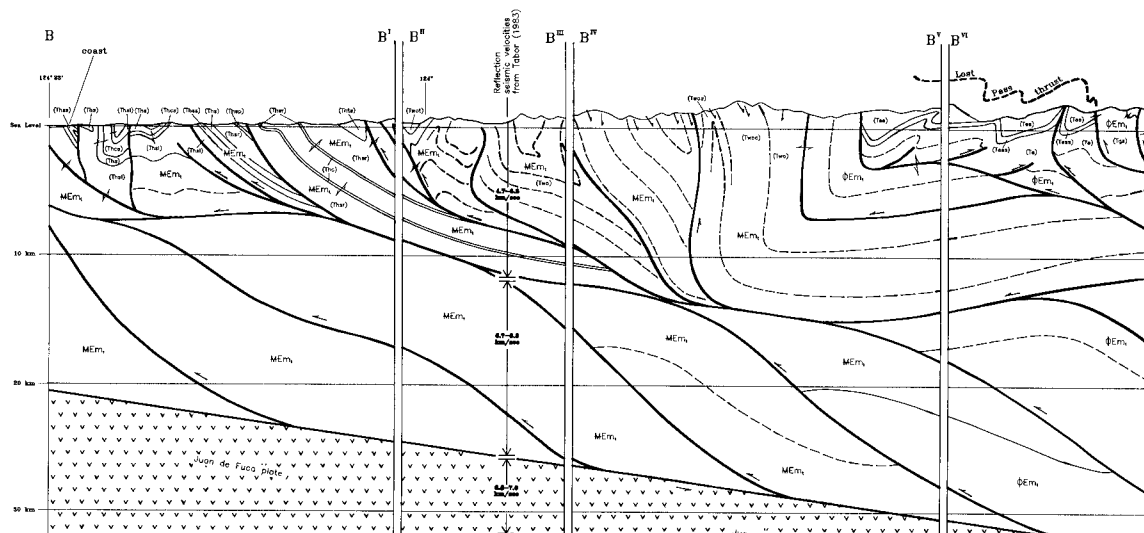


Figure 4. Structural cross-section of the western Olympic Peninsula to the Washington coast showing Miocene (M), Oligocene (O), and Eocene (E) marine strata (m). This section, which is about 50-miles long, illustrates structural styles typical of the Washington accretionary prism. Unpublished cross-section by S. E. Boyer, Charles Wright Academy, Tacoma, Washington.

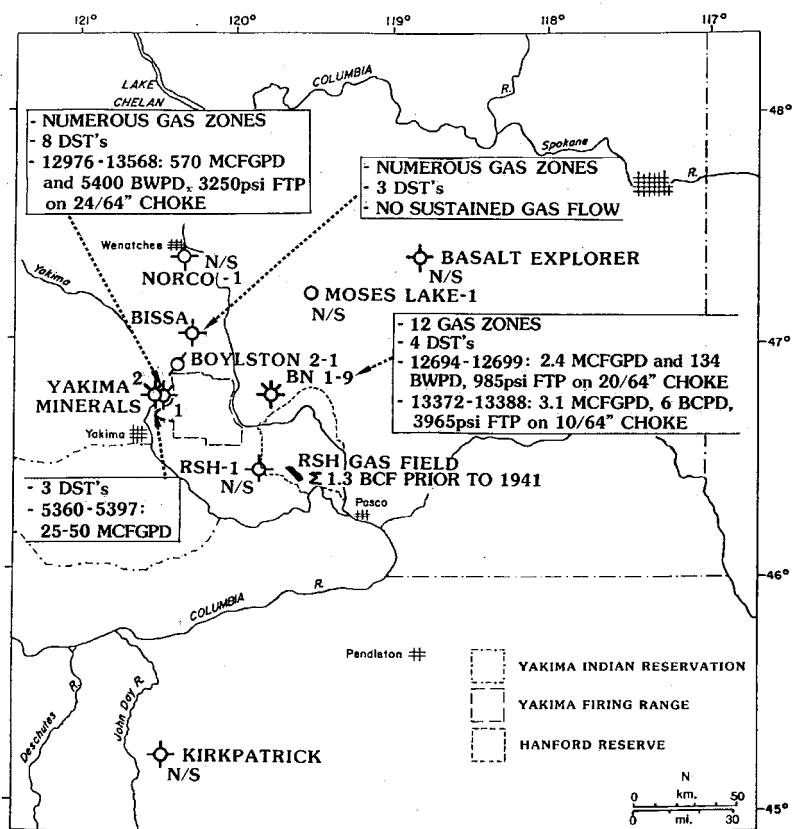


Figure 5. Petroleum shows and important wildcat wells in the Columbia Basin of Eastern Washington (from Lingley, 1995).

Gas-prone source rocks are present throughout the Eocene section, but available analyses are mostly from shallow wells that did not penetrate the gas-generative window (Fig. 6). Many wells that penetrated zones having vitrinite reflectance >0.7 logged good gas shows.

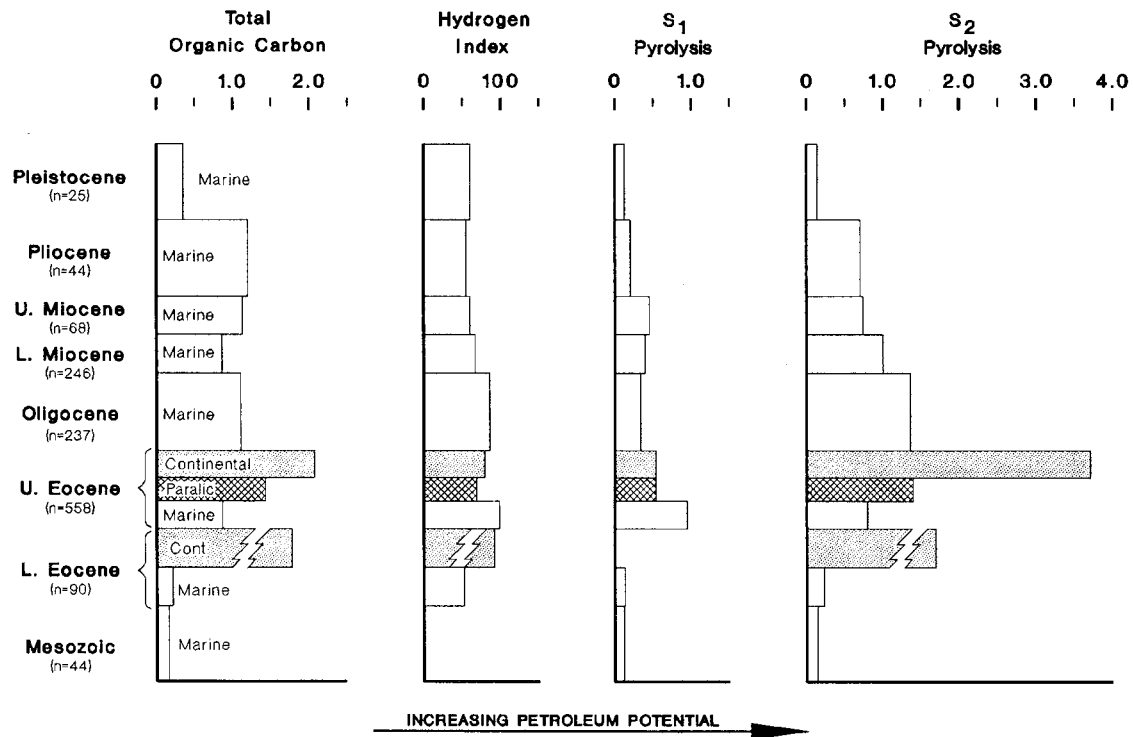


Figure 6. Summary of some geochemical characteristics of Tertiary strata in Washington State (from Lingley and Von der Dick, 1991). Low S_1 pyrolysis values generally reflect the fact that few wells have penetrated the gas-generative thermal regimes.

Reservoir quality appears to be comparable to Rocky Mountain sandstones (Johnson and others, 1997; Lingley and Walsh, 1986). In the Columbia Basin, wells typically encounter about 300-feet of sandstone having porosity in excess of 10 percent (Lingley, 1995). These include arkosic sandstone, which show a linear decrease in porosity with depth (Lingley and Walsh, 1986), and volcanogenic sandstones, which can have better porosity (Advanced Resources International, Inc., 1995). However, world-class reservoirs were logged in the Ocean City Oil and Gas Field and at the Jackson Prairie Gas Storage facility.

Blocks Nominated by the Washington State Department of Natural Resources

Approximately 9,000 acres of State lands have been nominated by industry for the November 3, 2005 lease auction. These nominated lands mostly underlie the Columbia and Yakima Rivers in the Columbia Basin, and are contiguous with the basin-centered gas play currently being tested by Encana's Anderville Farms No. 1 wildcat in Grant County. In addition, DNR will accept nominations for any other lands managed by the

Department for oil and gas prior to October 3, 2005. These are mostly shown on Plates 1 and 2.

The following brief descriptions outline DNR's ideas about five blocks, parts of which are proposed for auction on November 3rd. Please note that these blocks descriptions are based on very limited data and almost no subsurface information. Any exploration investment in these areas must be considered extremely speculative.

Chehalis Basin Depocenter

The Chehalis Basin is one of several local depocenters within the Puget—Willamette Trough (Finn and others, 1991) having sections of Eocene and Oligocene strata in excess of 15,000 feet (Figs. 1, 2). It shares some characteristics with the Portland Basin, which is located a few miles to the south and contains Mist, a faulted anticline that has produced more than 65 bcf of gas (Olmstead, 1985). These depocenters probably result from subsidence along one or more high-angle, oblique slip faults. Plays for basin-centered gas and coalbed methane may exist in the Chehalis Basin.

Although numerous wells have been drilled in the area, no wells have penetrated deeply into the gas-generative window owing to a combination of shallow drilled depths and low geothermal gradients west of the Cascade Range (Bustin, 1990, Walsh and Lingley, 1996). The deepest well in the basin, the Shell Thompson No. 1, drilled to 10,820 feet during 1962, bottomed near gas-generative temperatures, but also near the base of the volcanogenic sequence generally present in the middle of the Eocene section in most of Washington. This volcanogenic sequence may isolate shallow reservoirs from any thermally mature sources rocks below. Shallow source rocks include coal seams up to 50-feet thick, and related organic siltstones and shales. The distribution and quality of source rocks at depth are unknown, but potential exists for marine shale (Johnson and others, 1997). Strata elsewhere in this time-stratigraphic interval are potentially gas-generative (Lingley and von der Dick, 1991). The shallow section contains excellent reservoir sandstones including the main storage horizon at the Jackson Prairie Gas Storage facility, which is more than 150-feet thick and averages greater than 30% porosity.

Republic Graben

Gaylord (1986) reports about 10,000 feet of Tertiary Section in this northern, updip, extension of the Columbia River Basin including thick, organic-rich fluvial, deltaic, and lacustrine deposits, which are locally coal-bearing. This structurally complex feature is entirely untested, and as such, it is considered highly speculative.

Columbia Basin Block

This block contains several sections within the Yakima Fold Belt, a series of anticlines, each of which is several miles wide and tens of miles long. These are bounded by reverse-slip faults, which may verge north or south. Borehole and refraction data suggest that the fold belt results from interplay of the basalt cap and thickening in the underlying Eocene and Oligocene sedimentary sections.

This section consists of sandstones ranging in composition from arkose to volcanic-litharenite. Porosity in arkosic reservoirs diminishes as a linear function of depth (Lingley and Walsh, 1986), whereas some volcanogenic sandstones maintain fair to good porosity at depth (Advanced Resources International, Inc., 1996). Water flow rates up to 1,700 BWPD in the Yakima Minerals 1-33 well indicate good permeability.

Although only one shallow (biogenic?) gas field has been developed in the basin, three wells have had significant shows including the Shell BN 1-9 well, which tested an aggregate of 5.5 MMCFGPD from the Saddle Mountains anticline. The acreage offered by DNR in this area has local potential for conventional gas accumulations, and possibly basin-centered gas. It is proximal to the Encana Anderville Farms No. 1, which is currently drilling near the village of Mattawa in Grant County.

Horse Heaven Hills

Horse Heaven Hills is the largest of the Yakima Fold Belt structures; this combination fault/fold uplift is approximate 2 miles wide and 120 miles long. Astonishingly, it is yet to be tested. This block apparently shares stratigraphic and source rock characteristics with other parts of the Yakima Fold Belt described above.

North Columbia Basin Block

This area lies along the northern boundary of the Columbia Basin, as it is currently interpreted. This boundary is coincident with northwest-trending faults in the North Cascade Range, which may offer structural closure. This block apparently shares stratigraphic and source rock characteristics with other parts of the Yakima Fold Belt, but because it is entirely untested, any play in this block is considered highly speculative.